Biogeochemistry of Glacier Ecosystems

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Juneau Glacier Workshop, 5 March 2013

Spatial extent of glacier ecosystems is changing

Quantity of runoff is changing as well

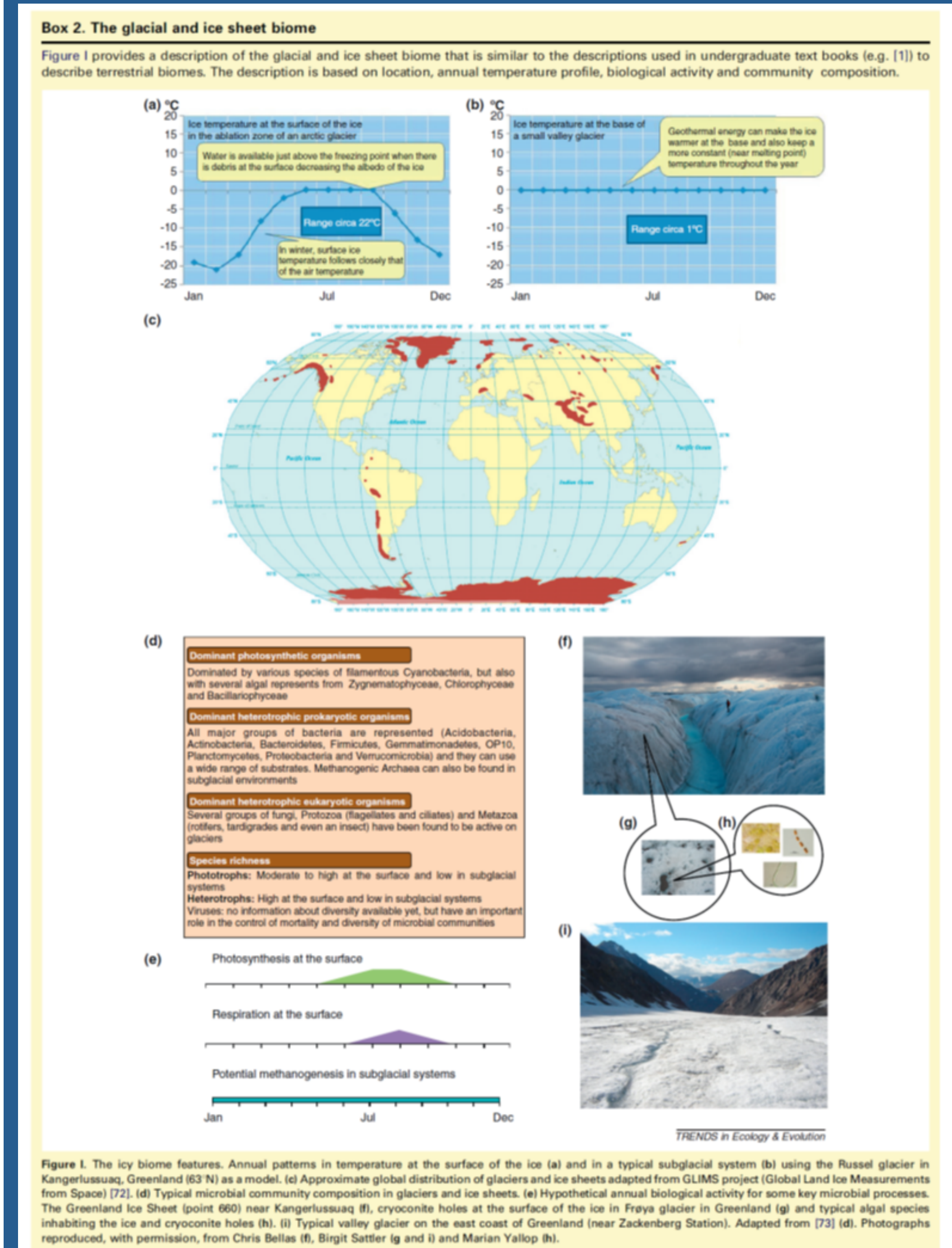

Box 2. The glacial and ice sheet biome

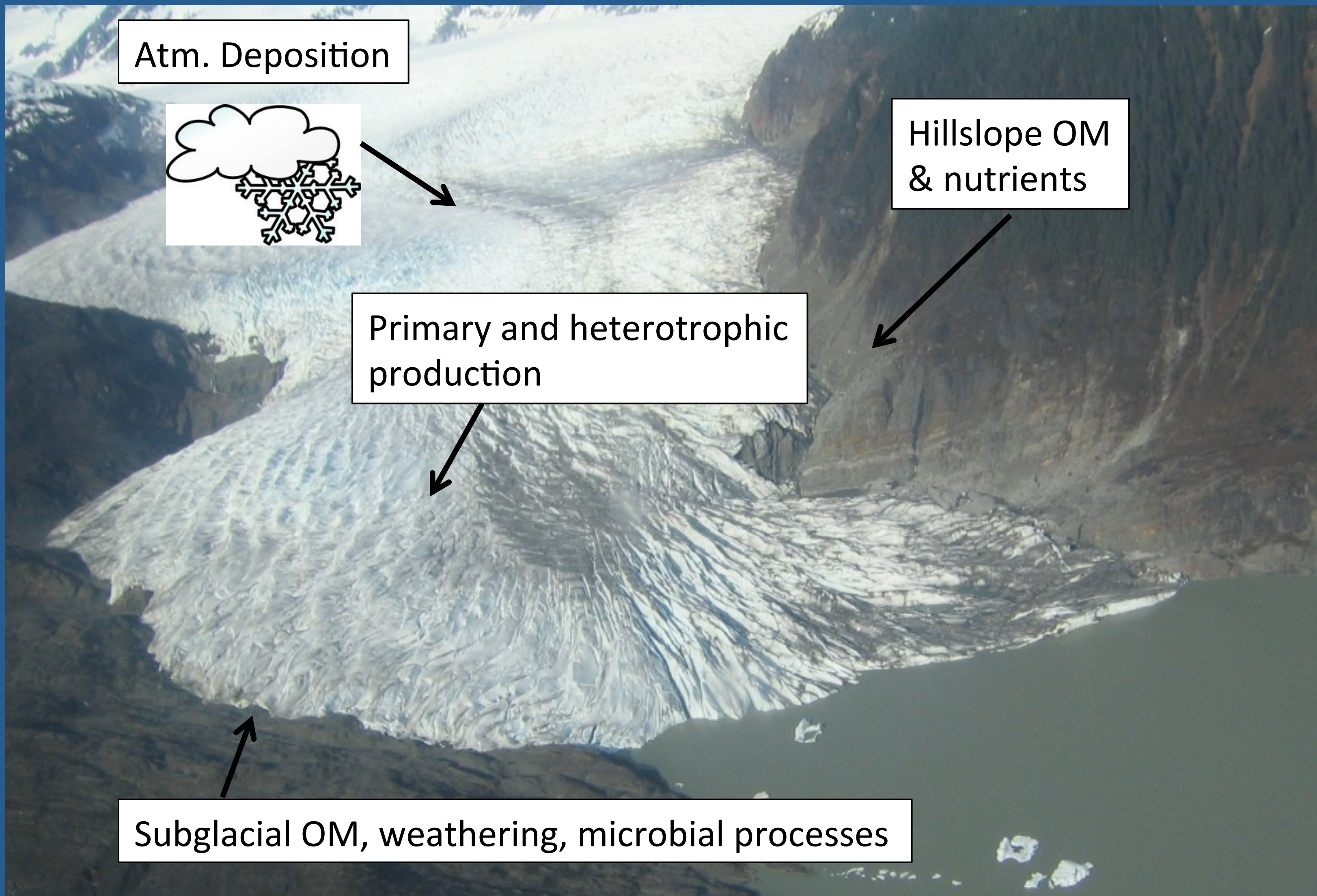
Figure I provides a description of the glacial and ice sheet biome that is similar to the descriptions used in undergraduate text books (e.g. [1]) to describe terrestrial biomes. The description is based on location, annual temperature profile, biological activity and community composition.

Figure I. The icy biome features. Annual patterns in temperature at the surface of the ice (a) and in a typical subglacial system (b) using the Russel glacier in Kangerlussuaq, Greenland (63°N) as a model. (c) Approximate global distribution of glaciers and ice sheets adapted from GLIMS project (Global Land Ice Measurements from Space) [72]. (d) Typical microbial community composition in glaciers and ice sheets. (e) Hypothetical annual biological activity for some key microbial processes. The Greenland Ice Sheet (point 660) near Kangerlussuaq (f), cryoconite holes at the surface of the ice in Frøya glacier in Greenland (g) and typical algal species inhabiting the ice and cryoconite holes (h). (i) Typical valley glacier on the east coast of Greenland (near Zackenberg Station). Adapted from [73] (d). Photographs reproduced, with permission, from Chris Bellas (f), Birgit Sattler (g and i) and Marian Yallop (h).

- Biogeochemically diverse
- Diverse and active micro-organisms
- Supraglacial and subglacial habitats
- Biological control on elemental cycling

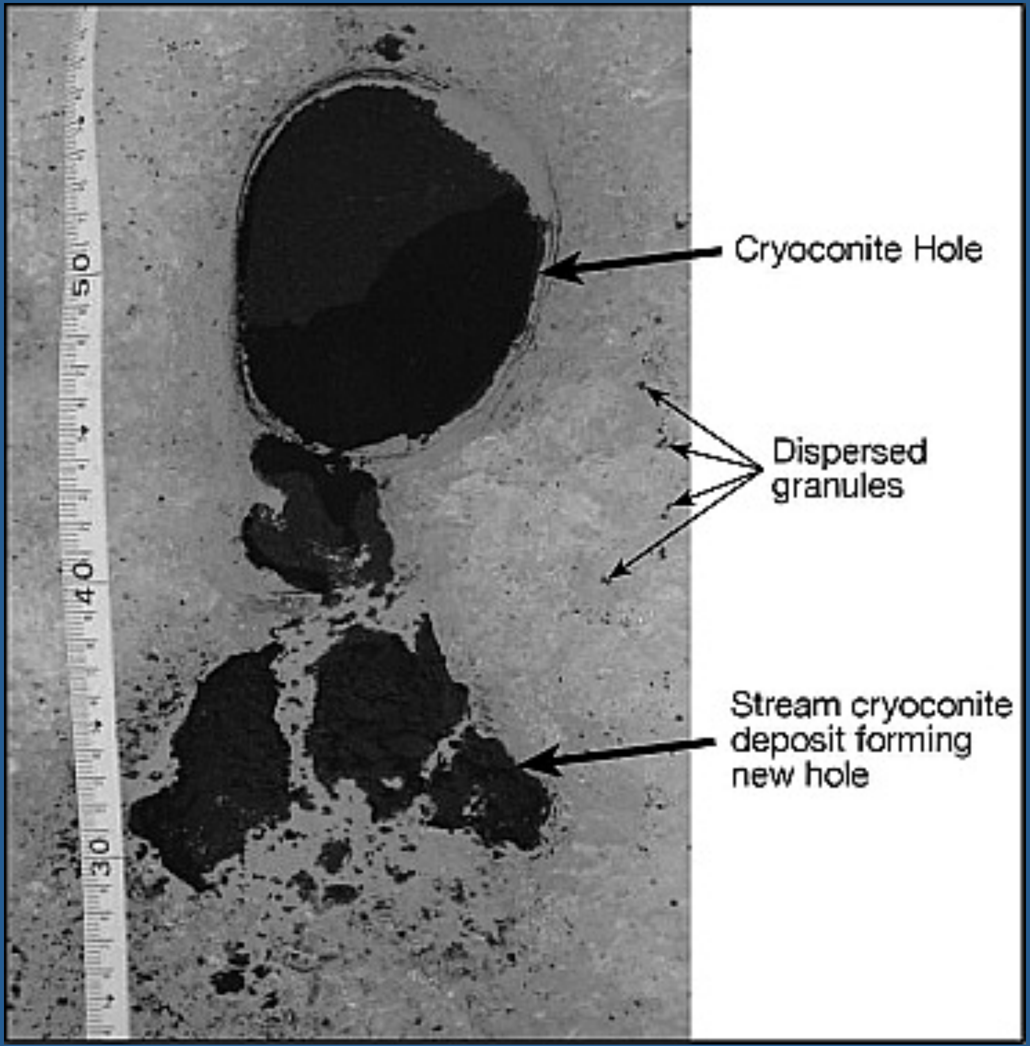
Anesio et al., 2012, Trends in Ecol. Evol.

Glacier Ecosystems



Supraglacial biogeochemistry

- Atmospheric deposition of organic matter, nutrients and contaminants
- Microbial habitats in cryoconite holes, deposits, and streams



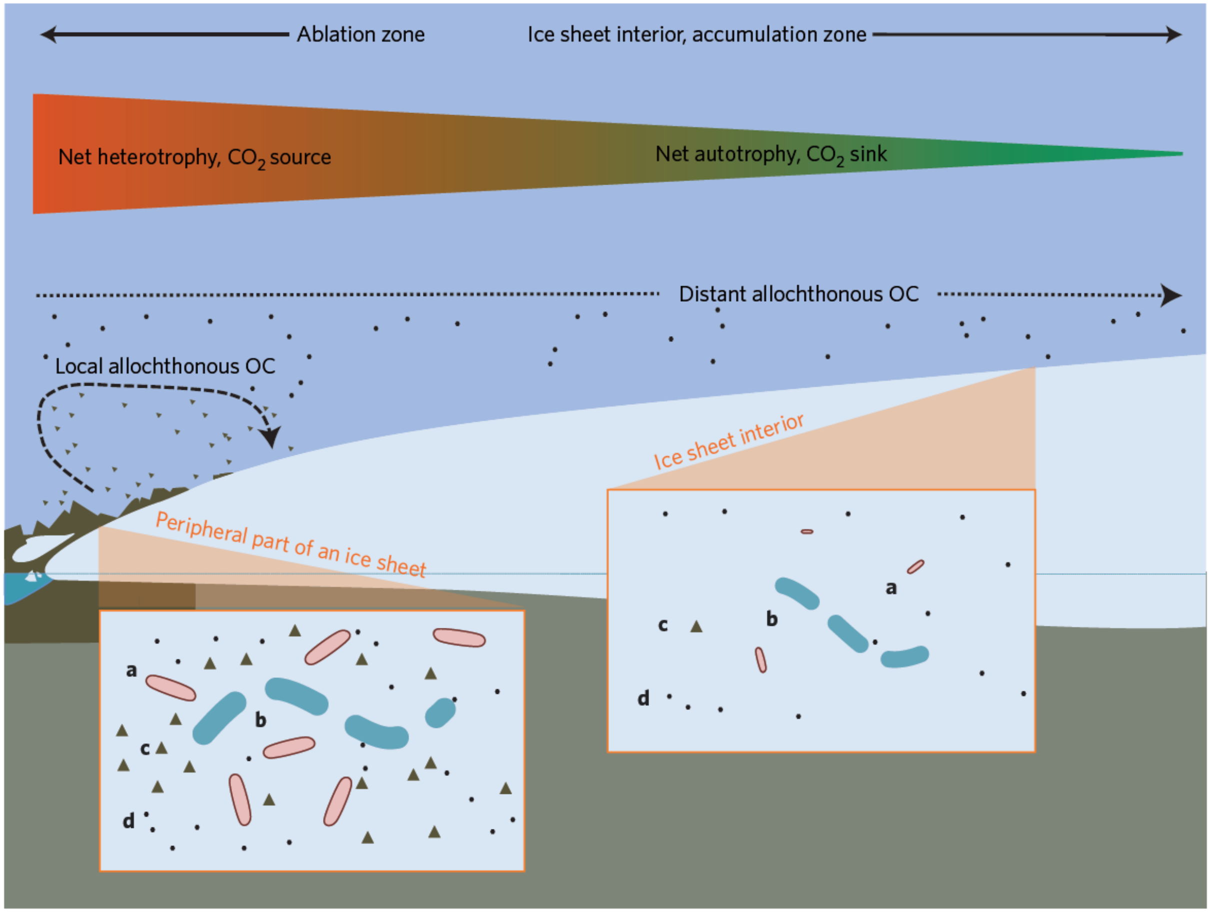
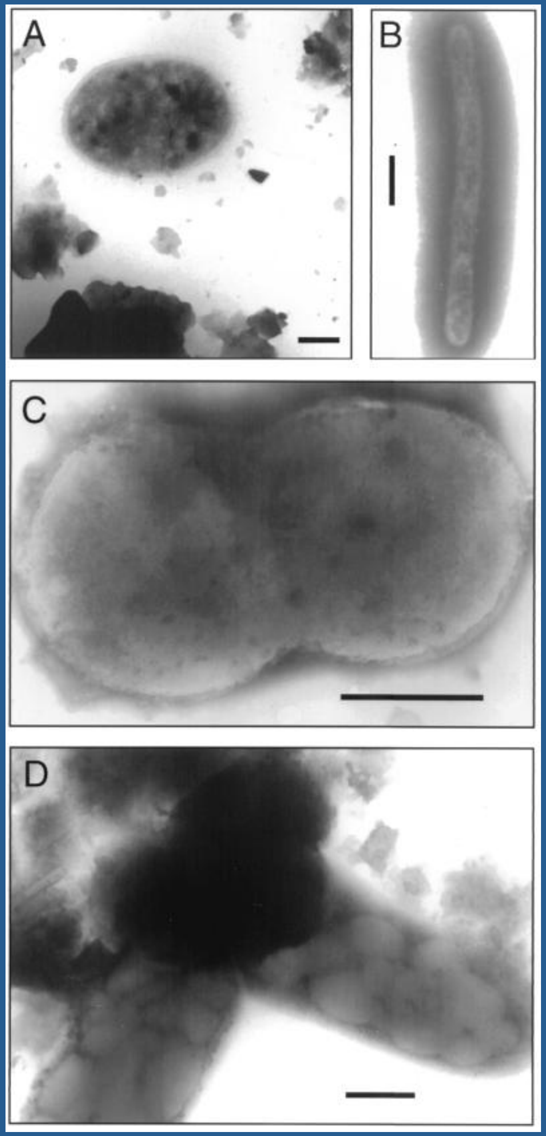


Figure 2 | Organic carbon (OC) sources and carbon balance in the supraglacial environment. Small glaciers and ice sheet margins (left inset showing a schematic of the ice surface) are more dynamic, receive more allochthonous OC and so are more likely to be CO_2 sources. Interiors of ice sheets (right inset) are more stable and likely to develop net autotrophy (that is, CO_2 sink). **a**, Heterotrophic microorganisms use OC as their carbon source. **b**, Photoautotrophic microorganisms fix CO_2 from the atmosphere and providing autochthonous OC for the system. **c**, Local allochthonous OC originates in adjacent deglaciated areas. **d**, Distant allochthonous OC, often of anthropogenic origin, is deposited as atmospheric aerosols.

Stibal et al., 2012, Nature Geoscience

Subglacial biogeochemistry

- Abundant microbial communities at the till/ice interface
- Inputs from supraglacial environments
- Processing of organic material and nutrients before export to rivers



Skidmore et al., 2000, App. Env. Microbiol.

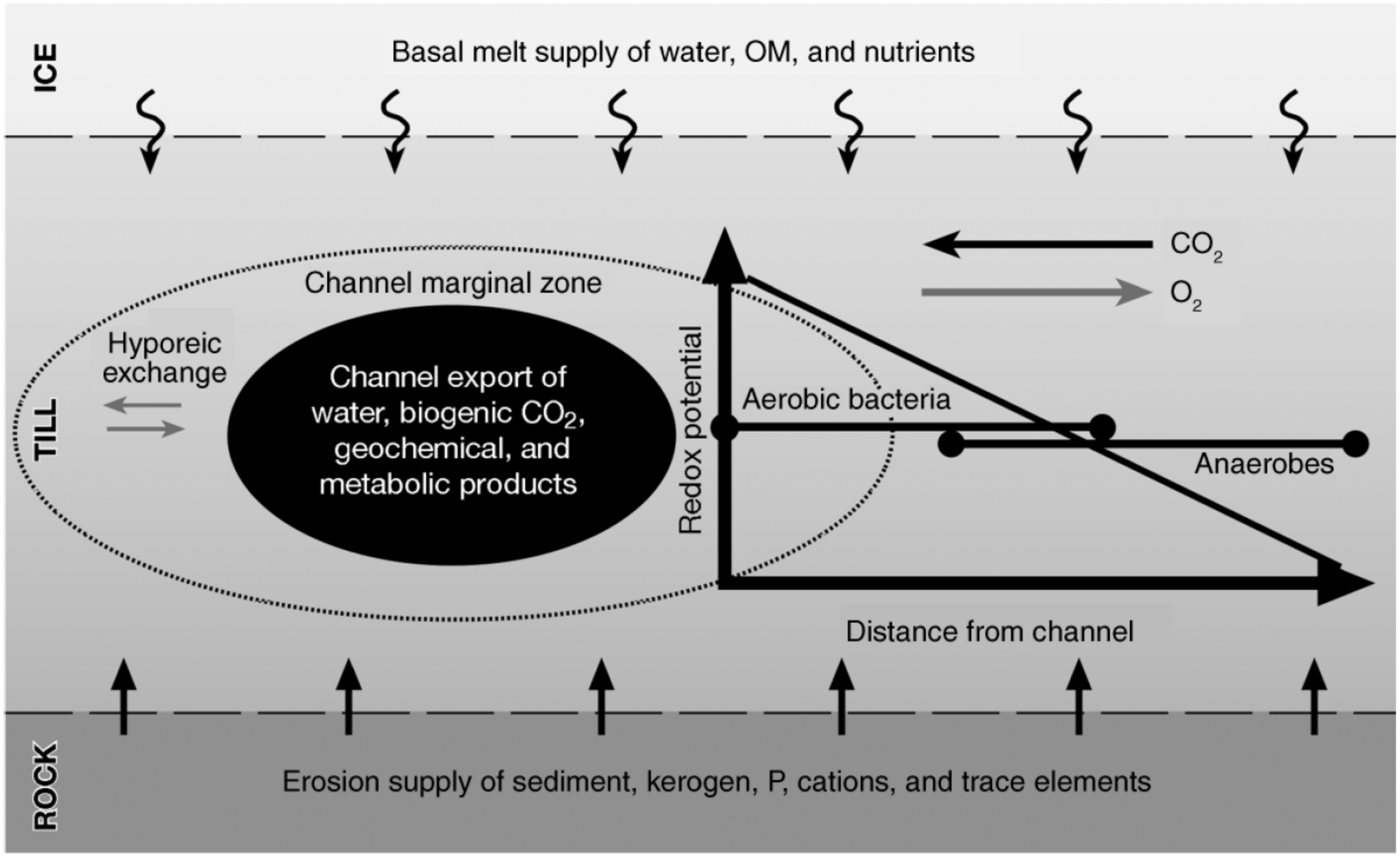


FIG. 9. Conceptual model of the relationship between hydraulic conditions at the glacier bed, the biogeochemical transfers that take place, and the broad types of bacterial activity. In the channel marginal zone (CMZ), regular (diurnally fluctuating) exchanges take place between pore waters in the till and channel waters otherwise in transit. "OM" is organic matter.

Hodson et al., 2008, Ecol. Monographs

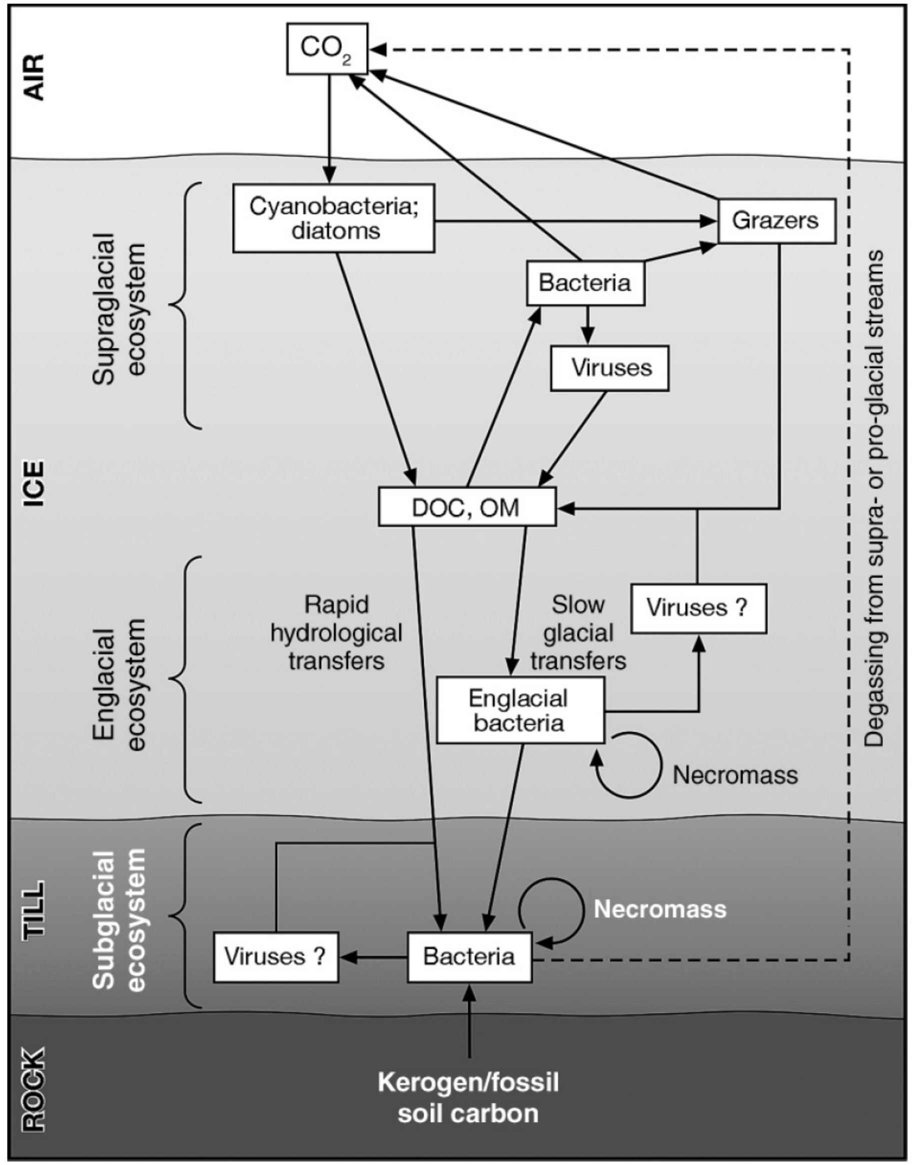


FIG. 10. Carbon flows through glacial food webs. "DOC" is dissolved organic carbon, "OM" is organic matter, and "Necromass" refers to OM produced from in situ bacteria.

Hodson et al., 2008, Ecol. Monographs


Glacier Runoff

What do we know?

Ecosystem Structure

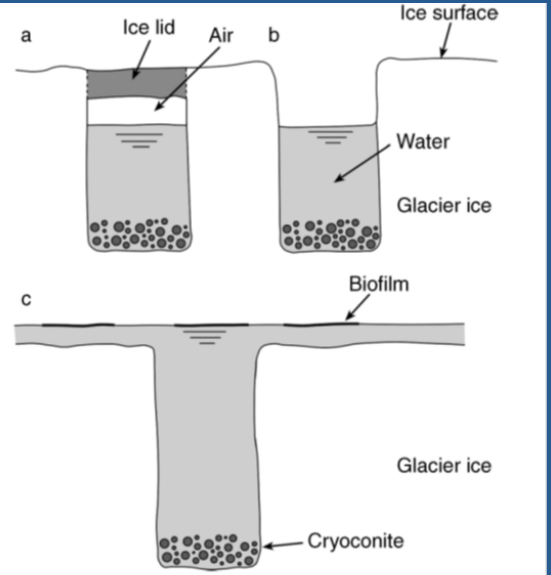
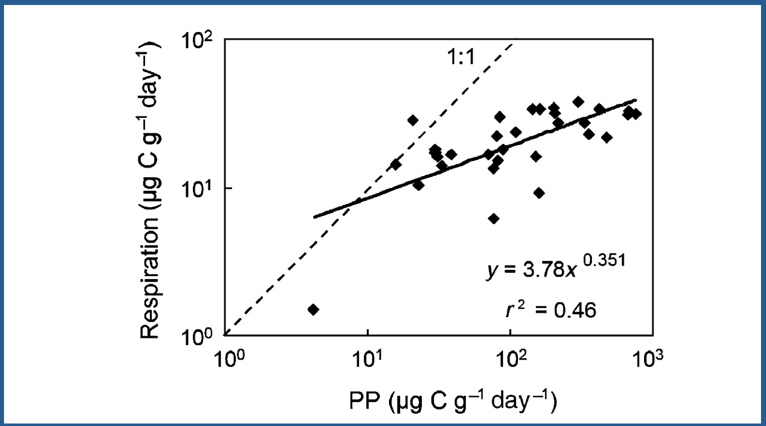


Fig. 6. Anatomy of a cryoconite hole, showing (a) closed, (b) open, and (c) submerged morphologies.

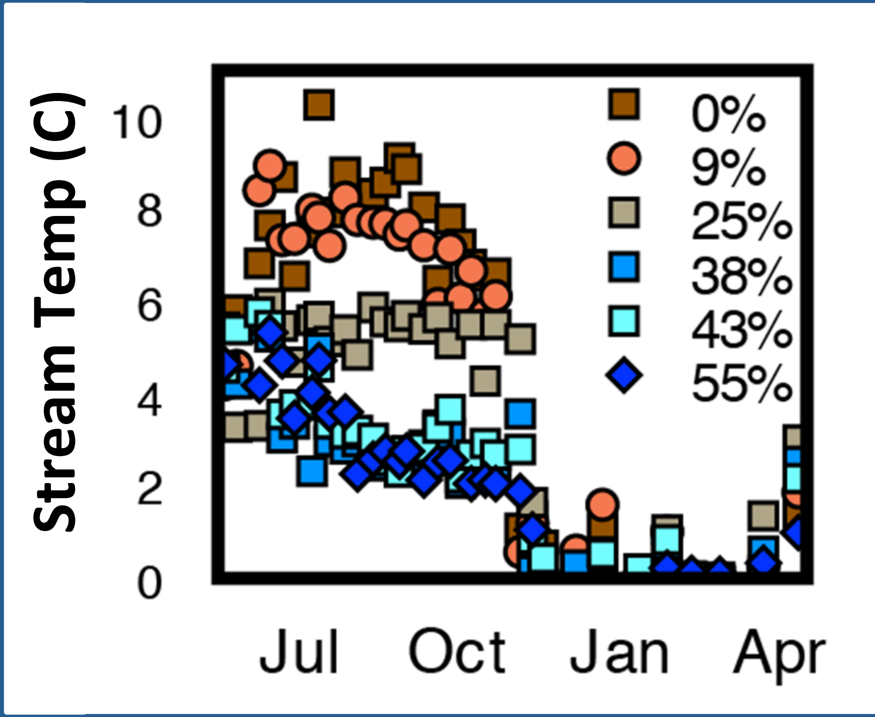


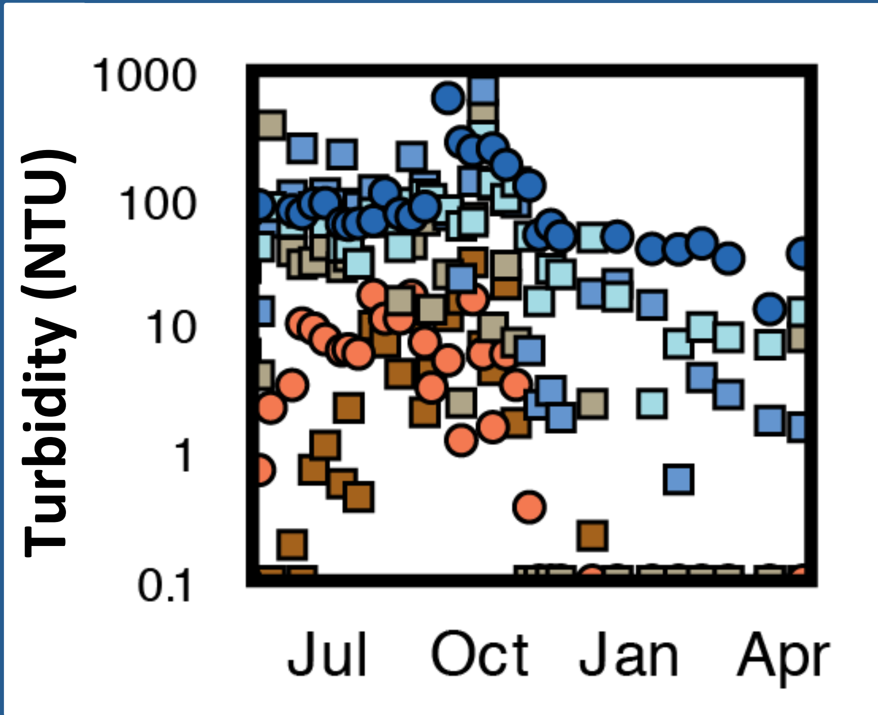
On a global basis cryoconite holes have the potential to fix as much as 64 Gg of carbon per year.

Most lakes and rivers are generally considered as heterotrophic systems, but our results suggest that glaciers, which contain 75% of the freshwater of the planet, are largely autotrophic systems.

Anesio et al., 2009, Global Change Biology

Physical properties of rivers





Hood and Berner, 2009, JGR

Riverine Biodiversity

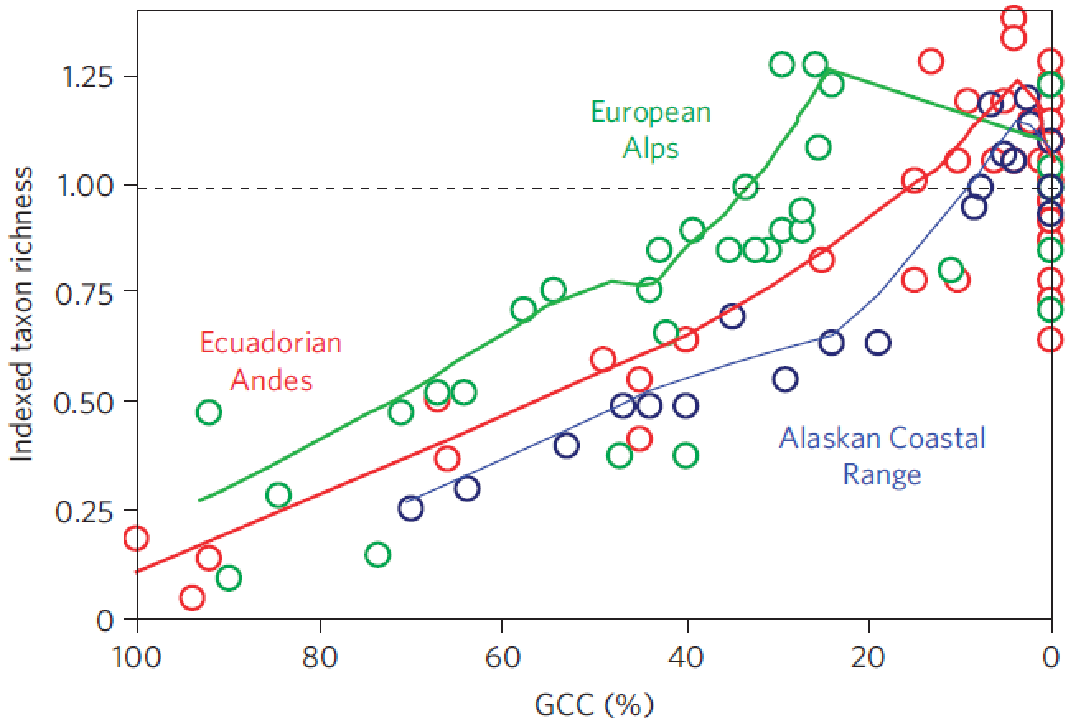
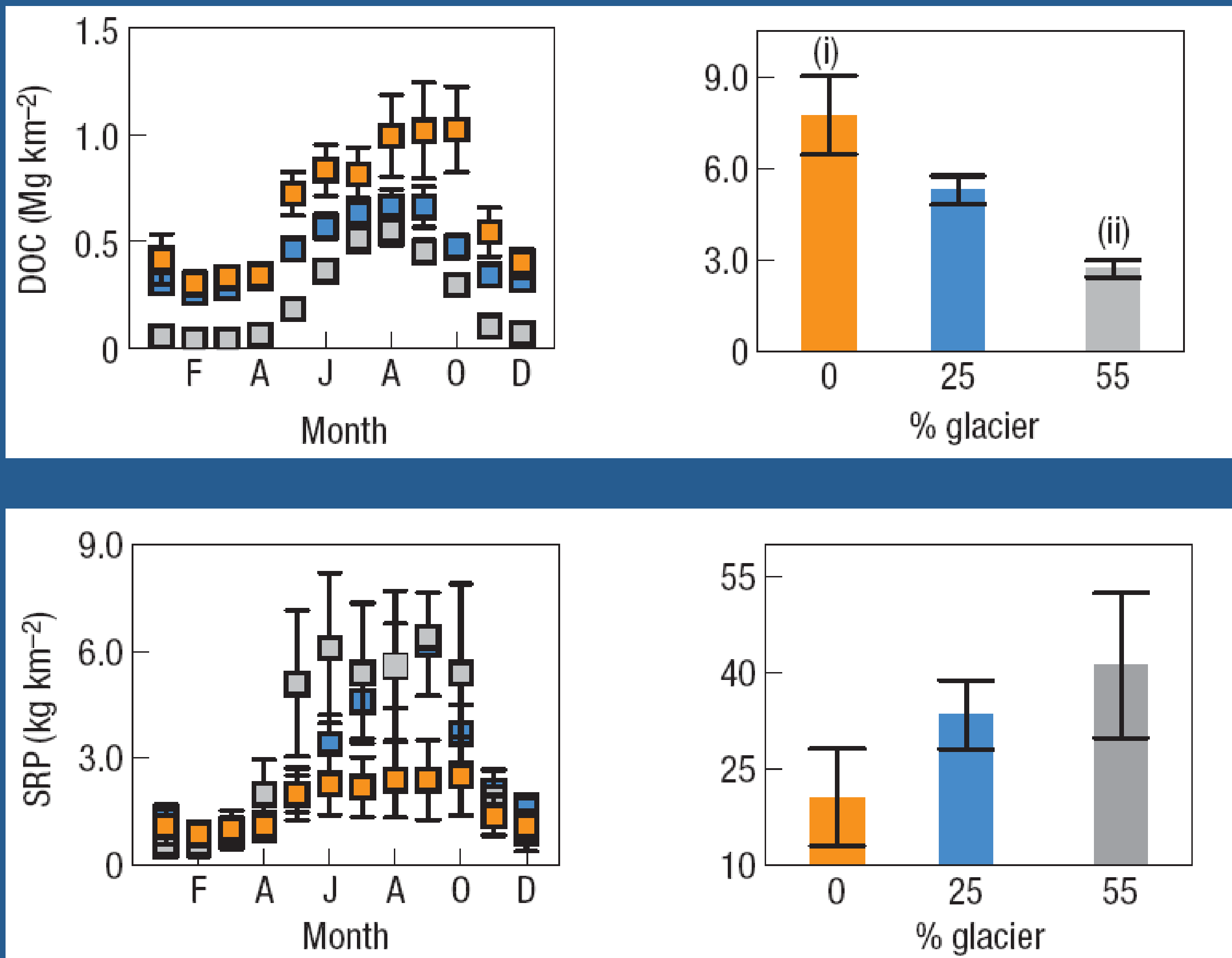


Figure 3 | Local richness (α diversity) as a function of glacial cover. The data shown are for species richness (Alaska) and family richness (Ecuador and Alps). Local taxon richness peaks at 5–30% GCC. Data are indexed to 1, indicated by the horizontal dashed line, at non-glacial sites (0% glacial cover). Each data point represents a river site and lines are Lowess fits.

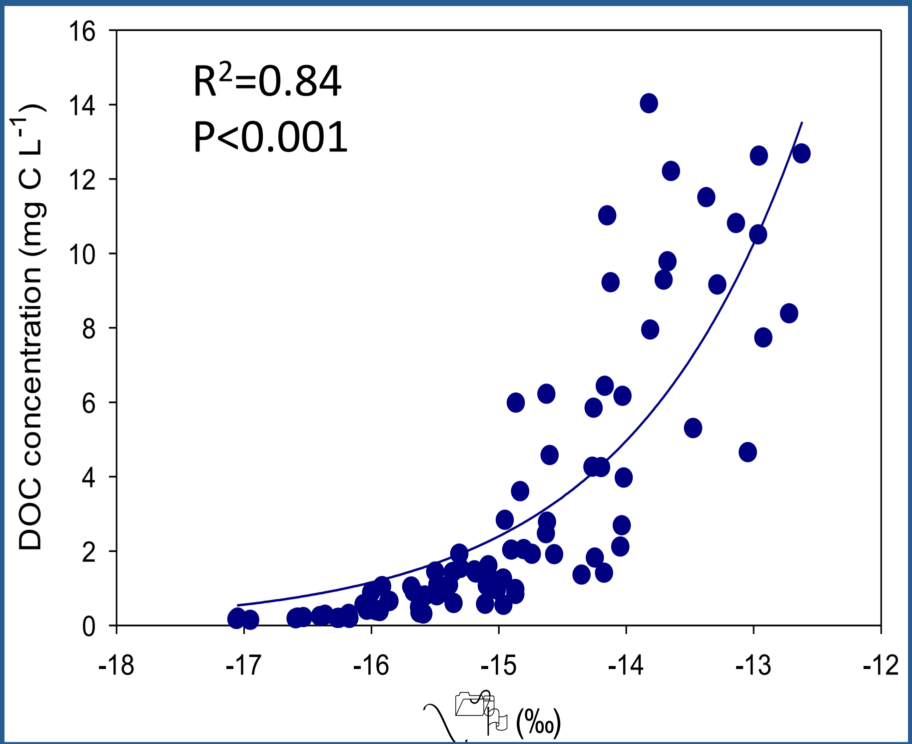
Jacobsen et al., 2012, Nature Climate Change

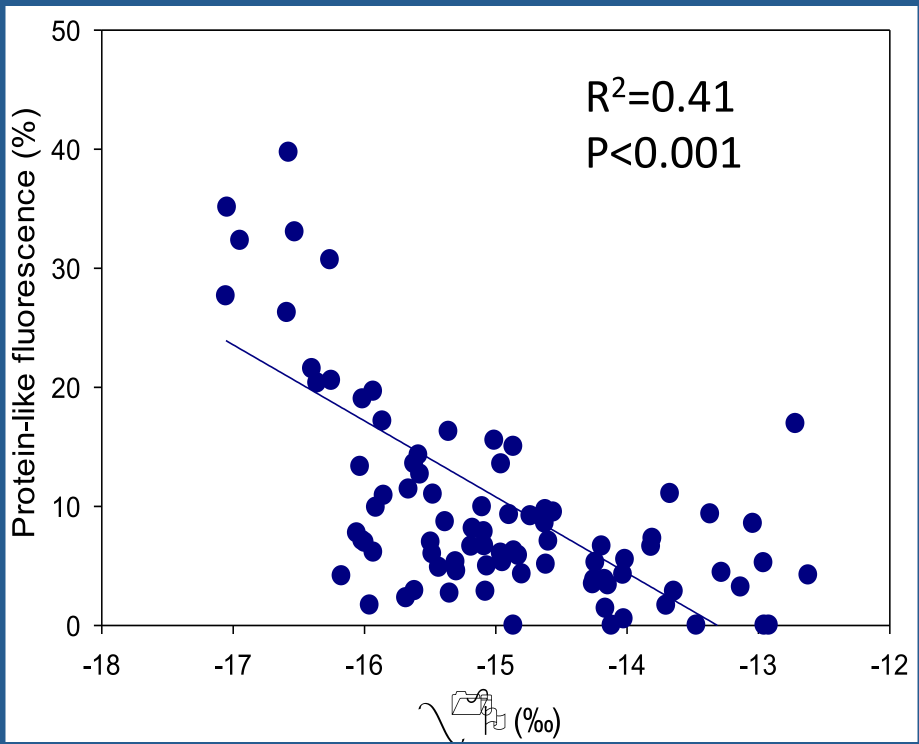
Nutrient Export in Rivers



Hood and Scott, 2008

Riverine Organic Matter

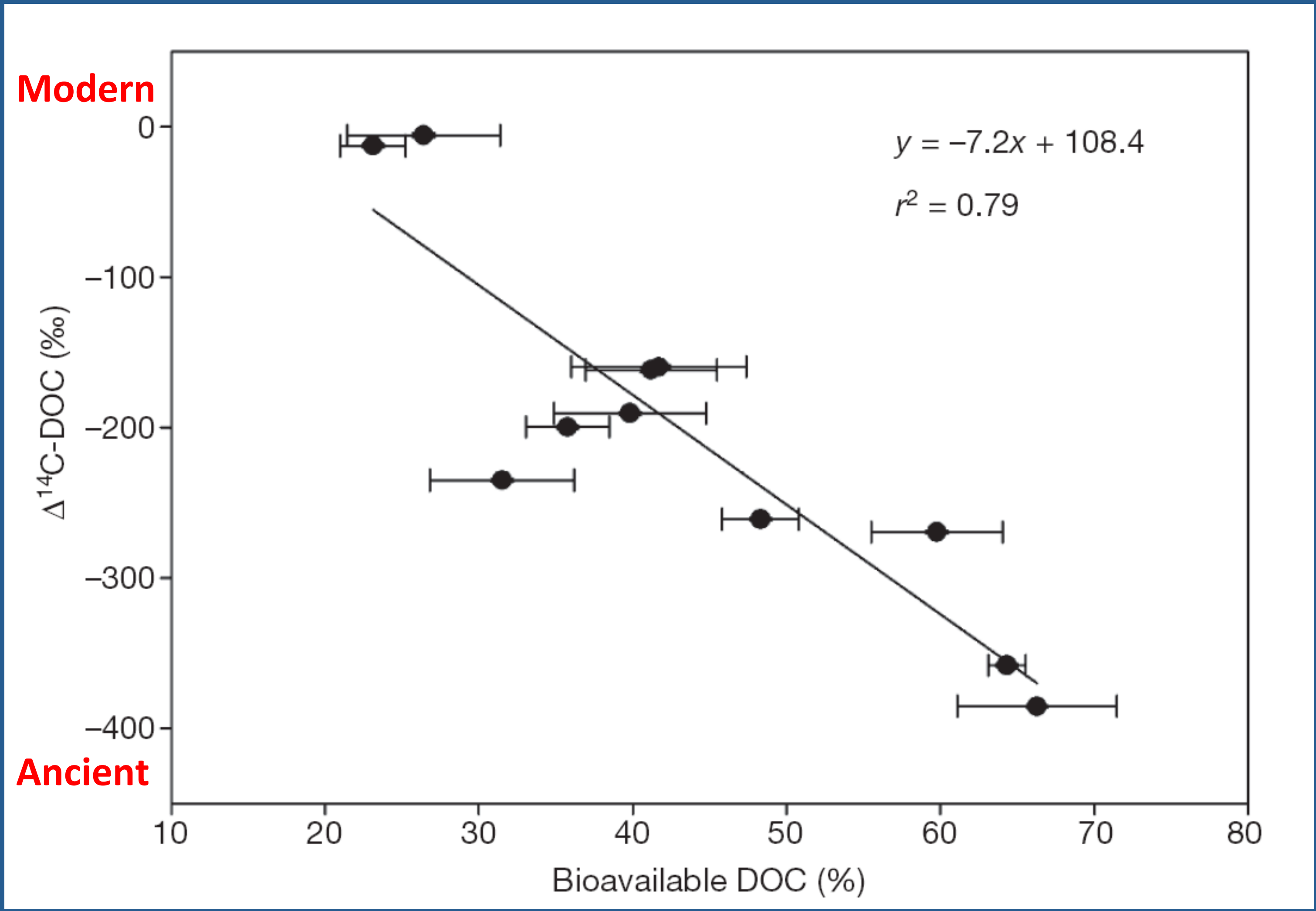




Glacier runoff strongly influences the chemistry of downstream rivers

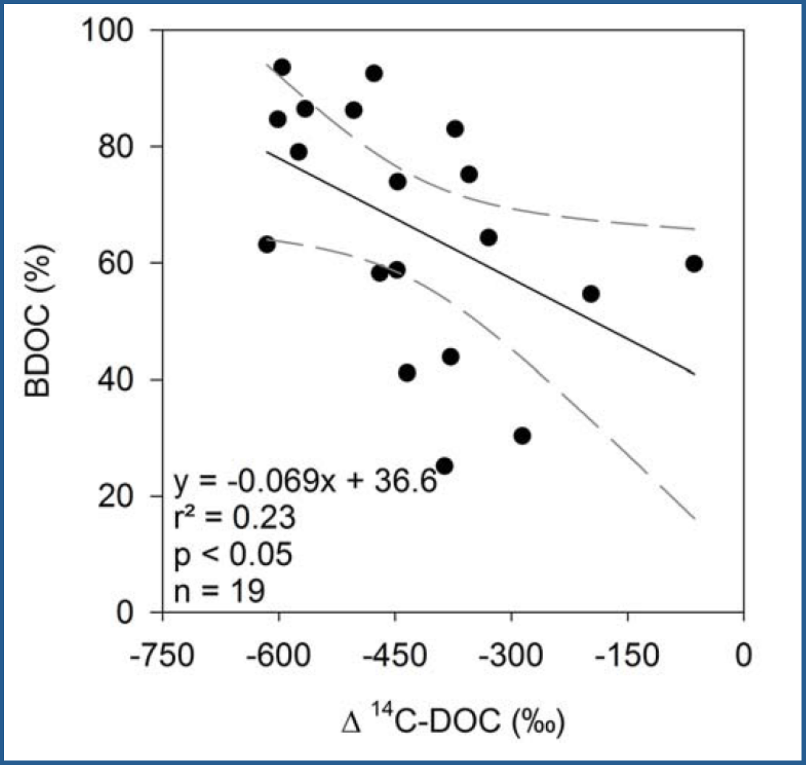
Fellman et al., unpublished

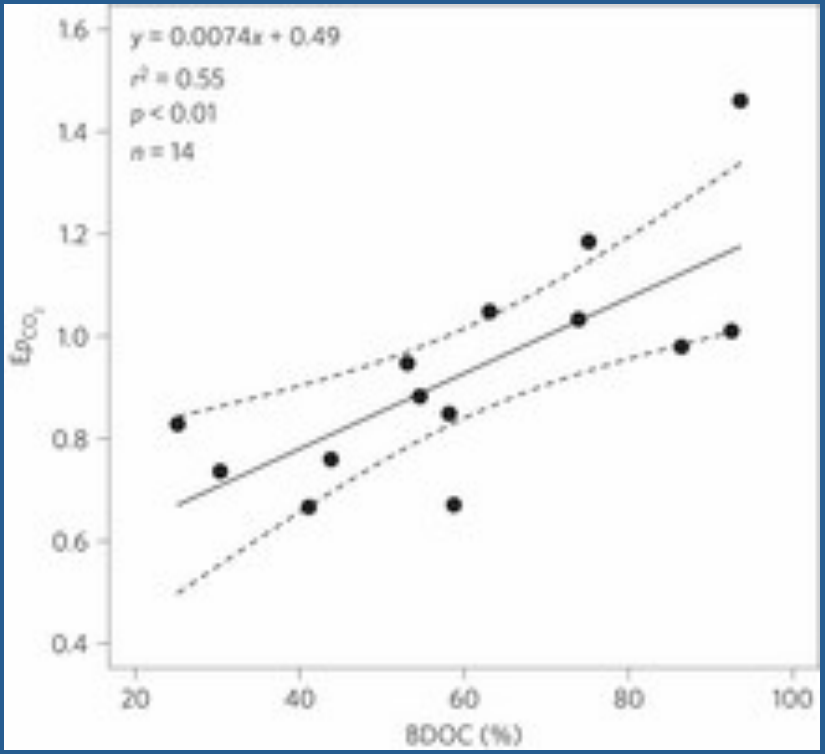
Carbon Age and Bioavailability



Hood et al., 2009, Nature

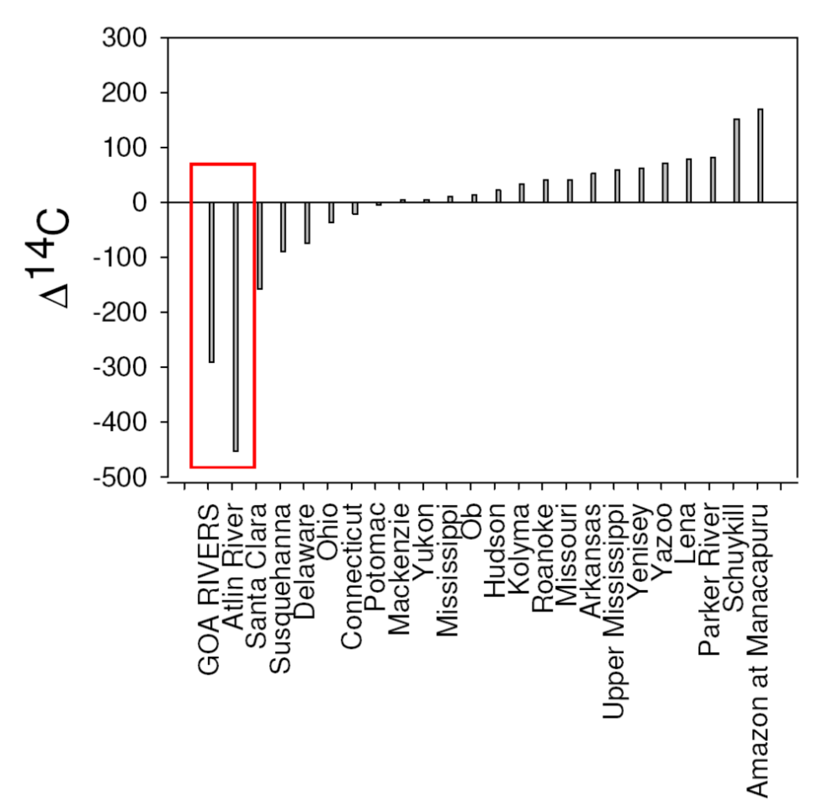
Riverine Carbon Subsidy

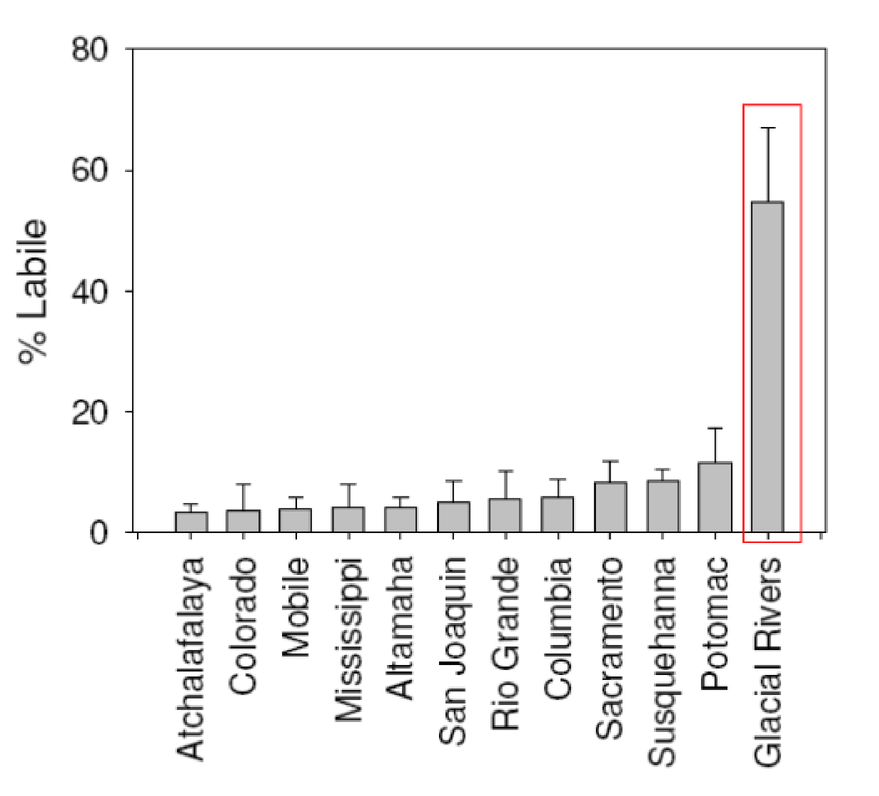




Singer et al., 2012, Nature Geoscience

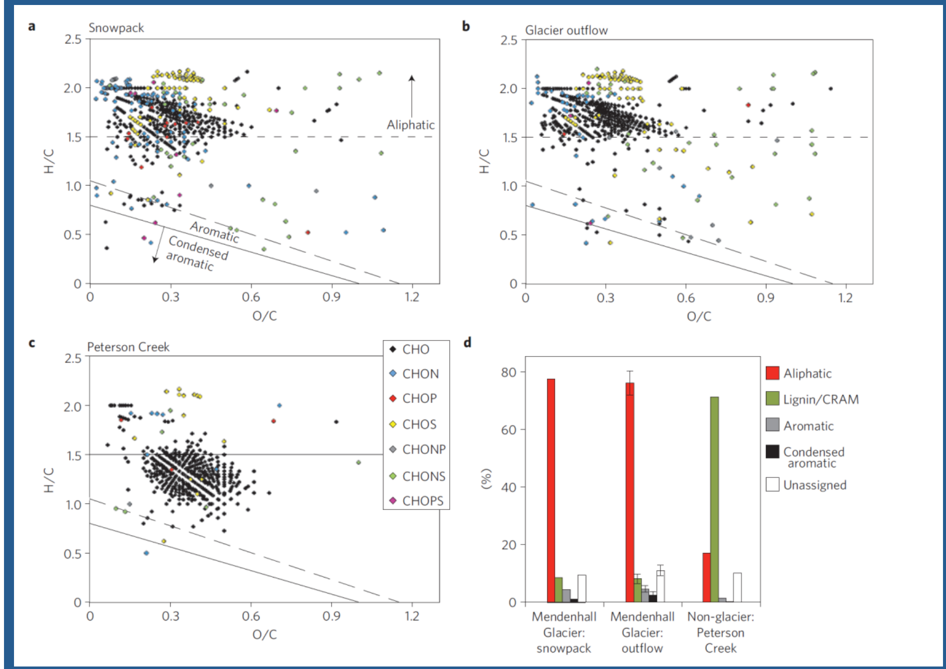
Glacier-derived Organic Matter

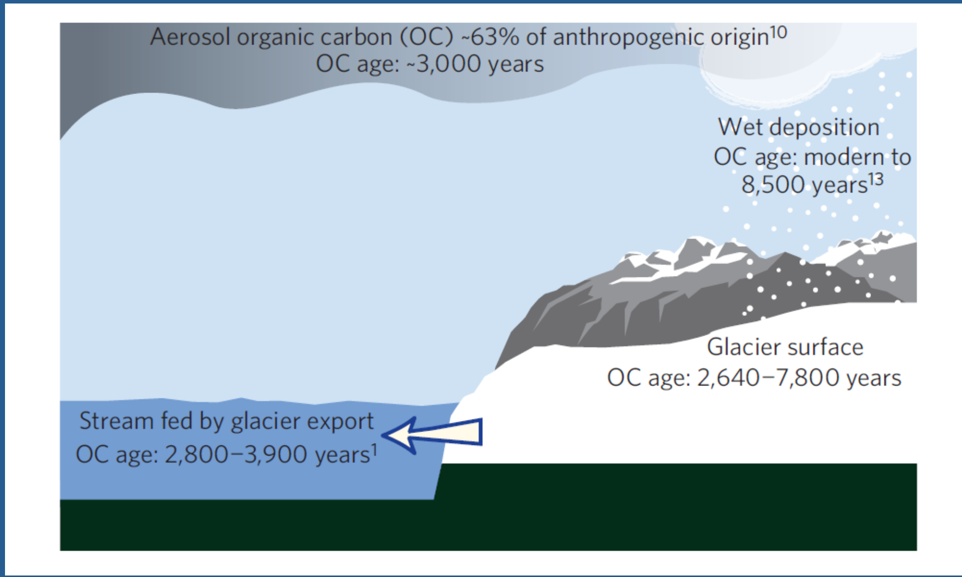




Raymond et al., unpublished

Anthropogenic Influence?





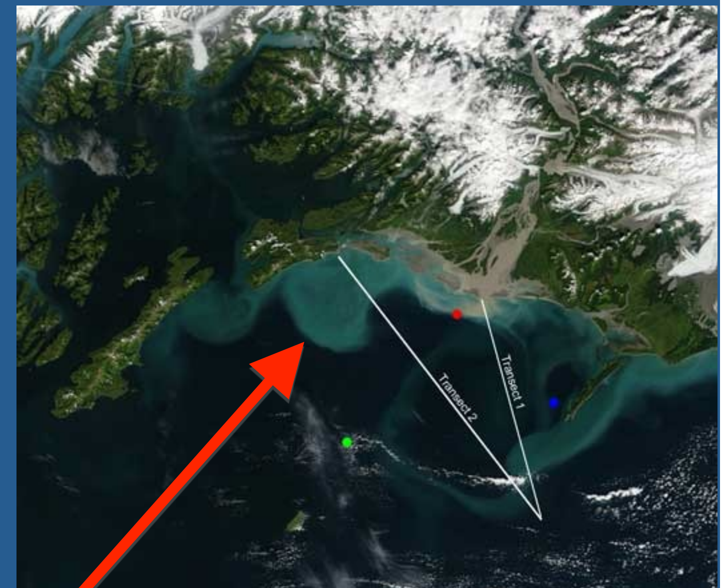
Stubbins et al., 2012, Nature Geoscience

Glacier Organic C fluxes

DOC export = 12-18 kg C/ha/yr

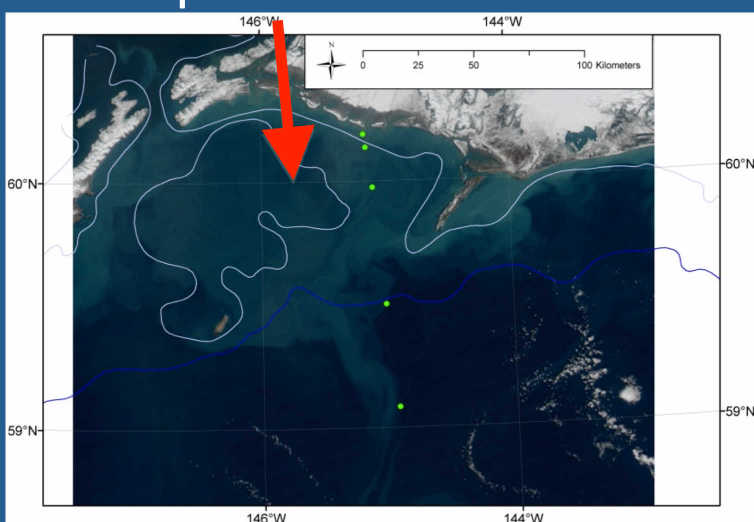
DOC export = 22-86 kg C/ha/yr
(Laudon et al., 2004;
Kortelainen et al., 1997)

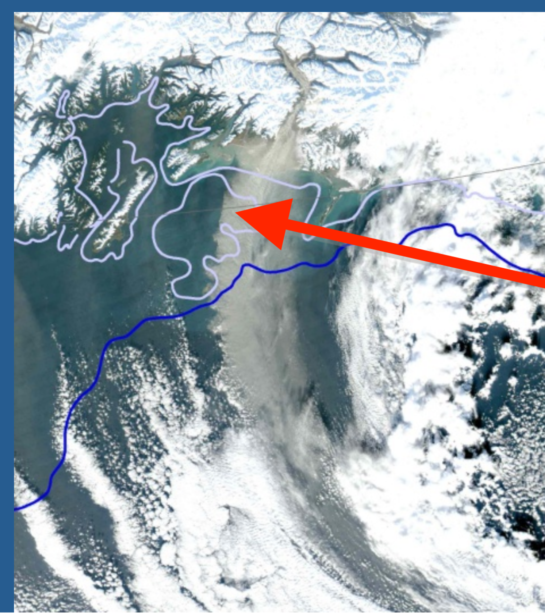
Glaciers as a Marine Fe Source



Glacier River Plumes

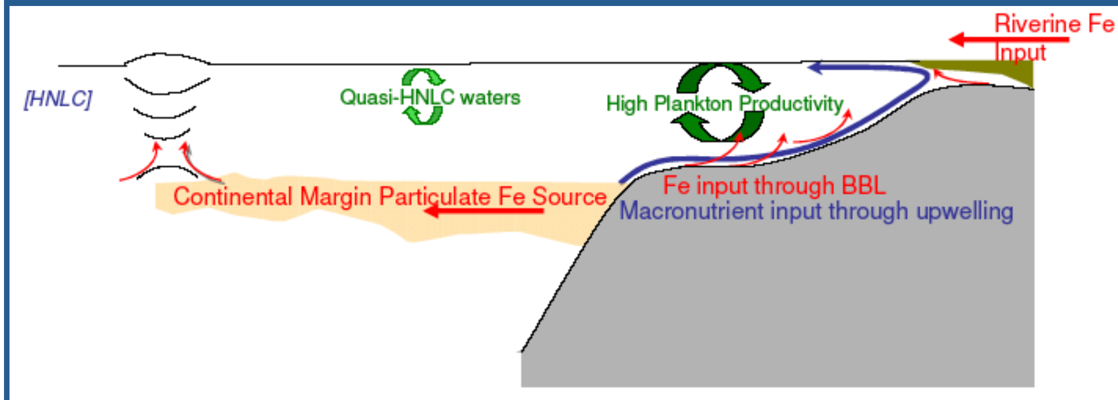
Resuspended Glacial Flour





Glacial Flour Dust Storms

Coastal Mixing of Riverine Fe and Marine Nitrate



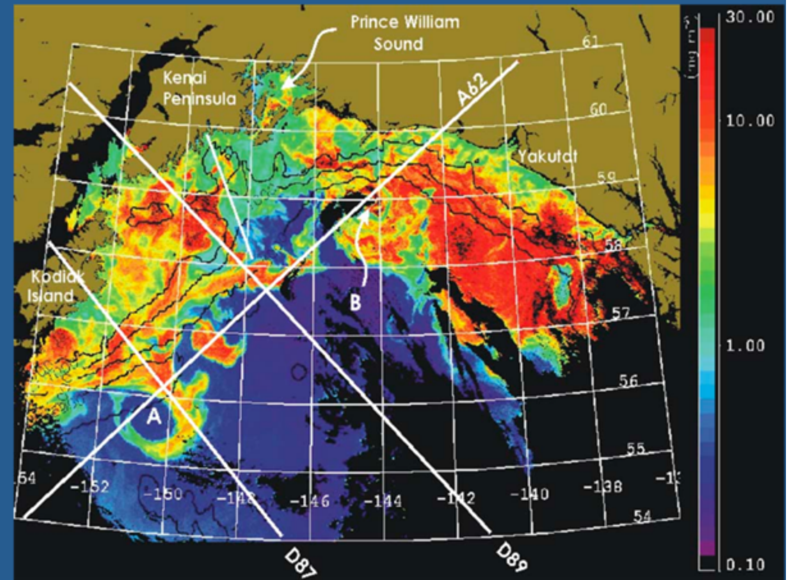
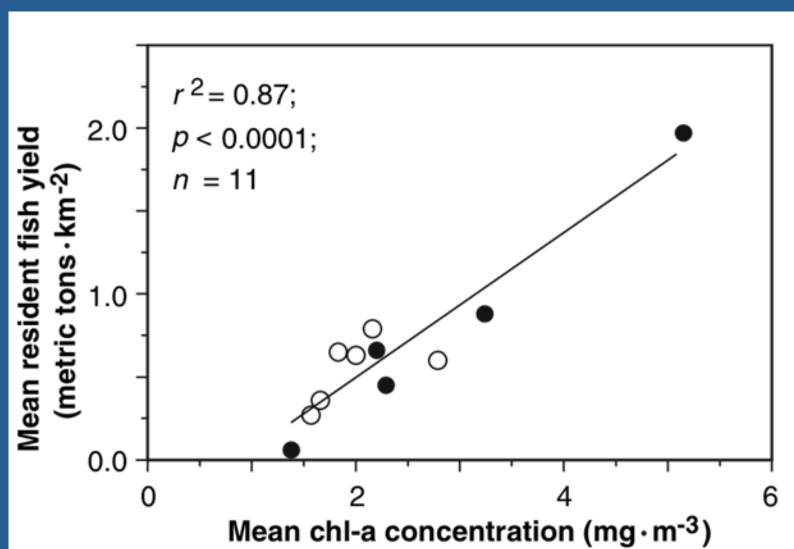
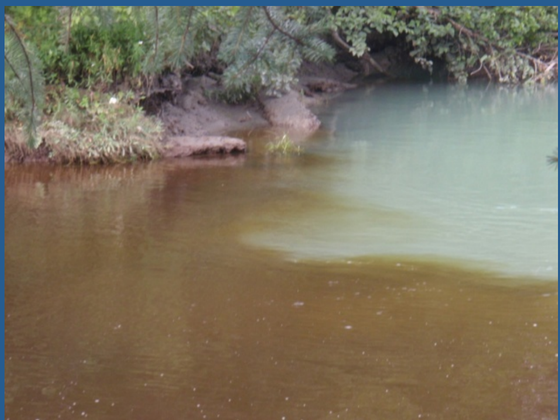


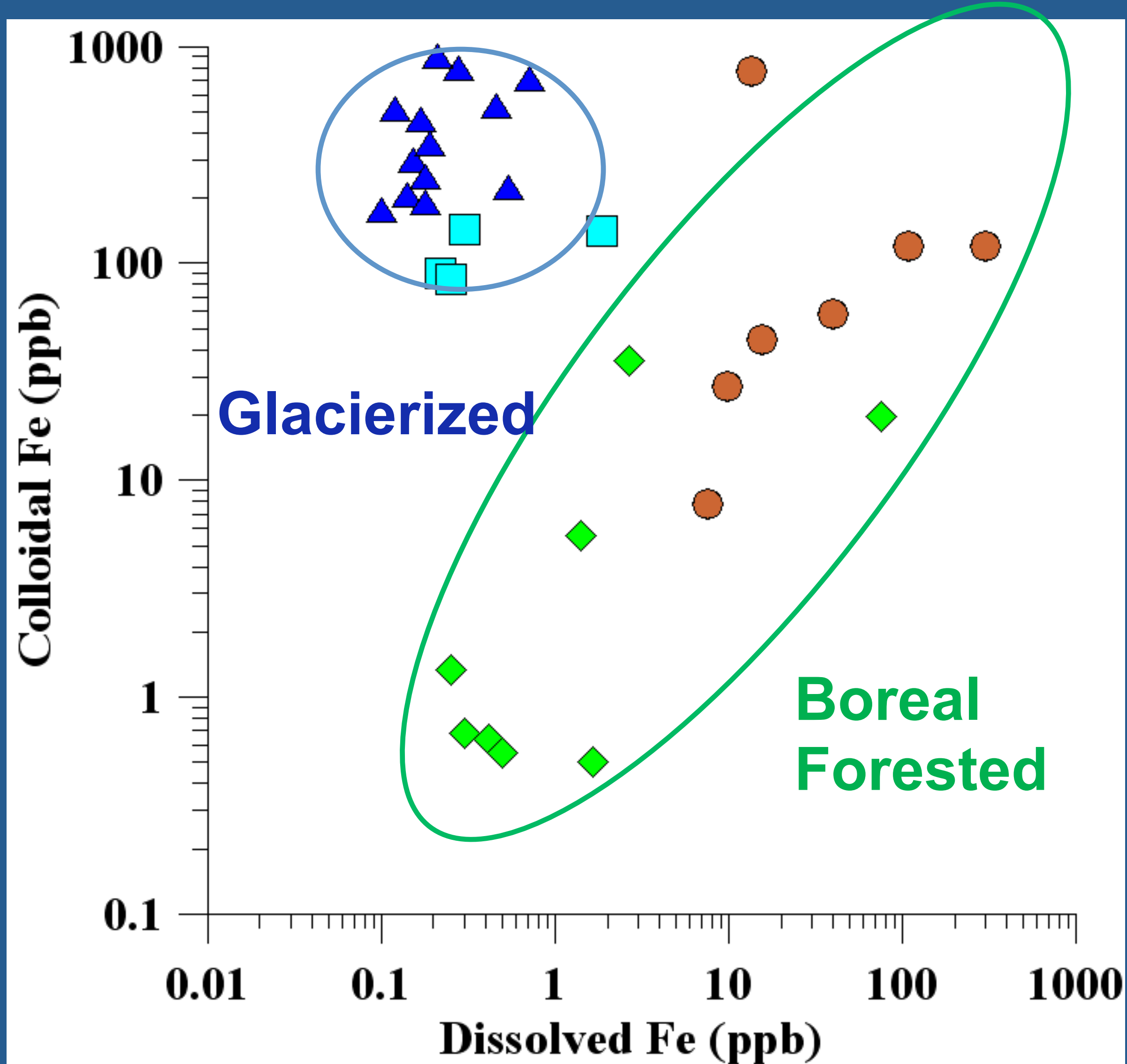
Figure 1. SeaWiFS false-color image of chlorophyll pigment concentration in the Gulf of Alaska on 10

Ample nutrients drive productivity and fisheries



Fe Solubility by River Type





Schroth et al., 2012, GRL

Glaciers as a Contaminant Source

Blast from the Past: Melting Glaciers as a Relevant Source for Persistent Organic Pollutants

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Melting Glaciers: A Probable Source of DDT to the Antarctic Marine Ecosystem

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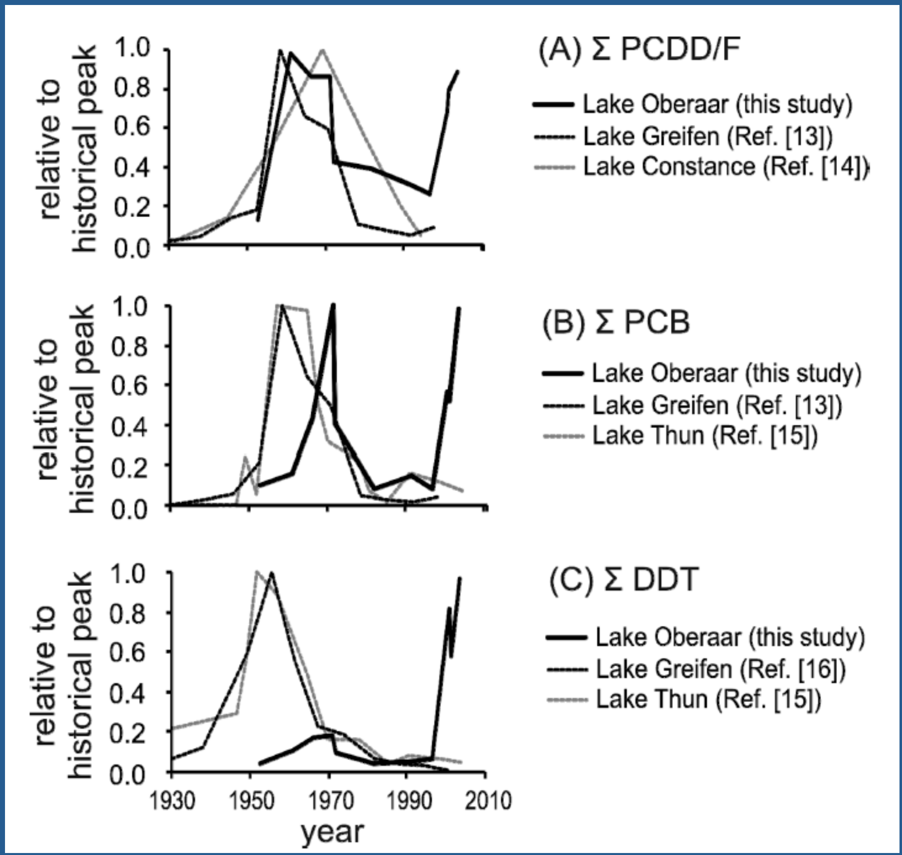
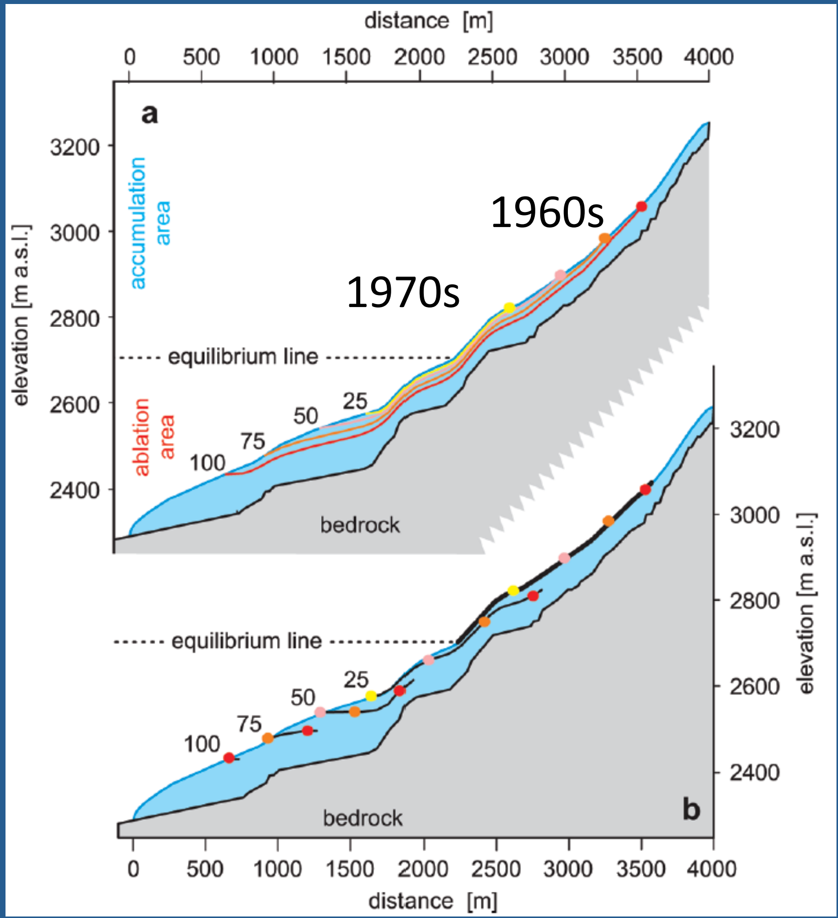
Dynamics of Contaminant Release



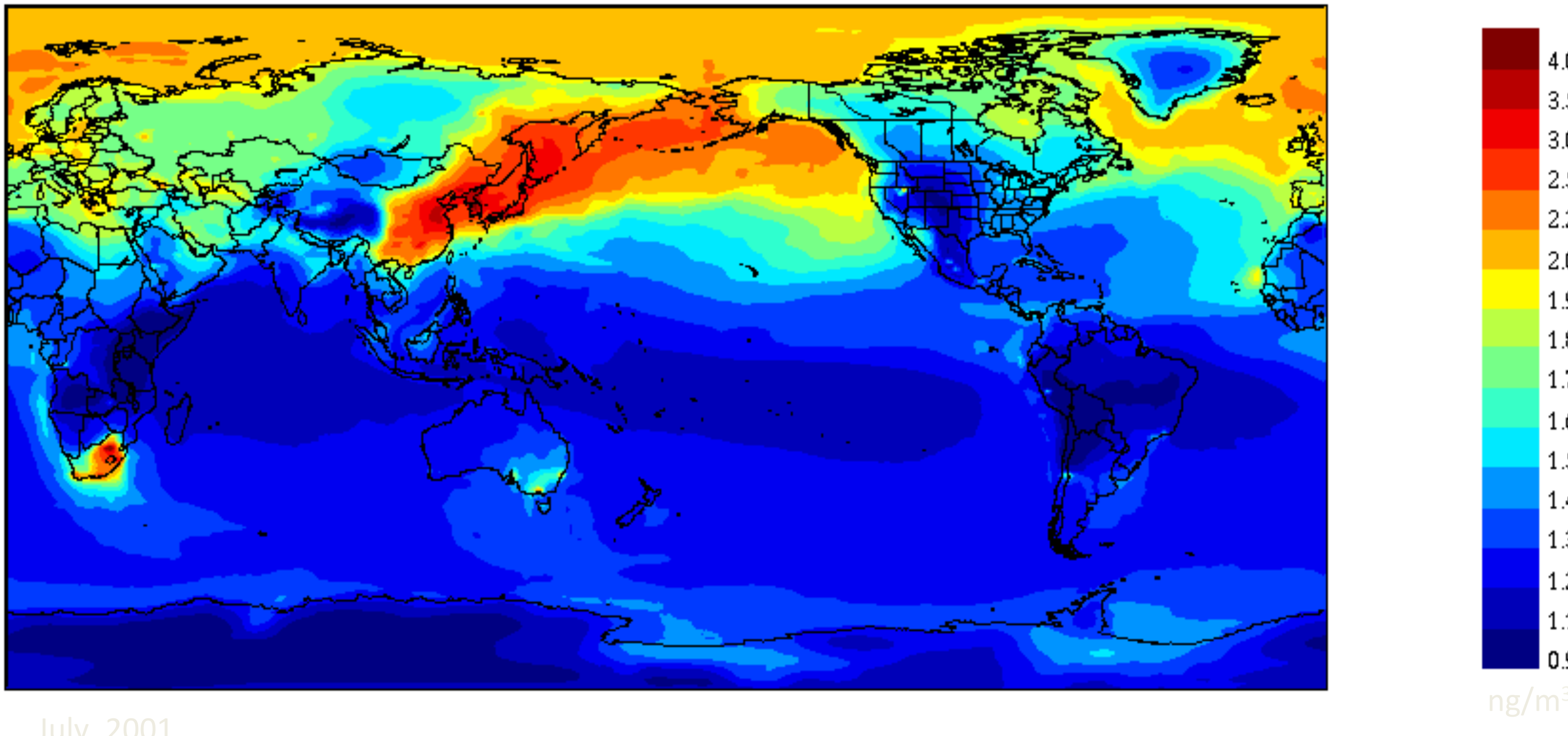


Bogdal et al., 2009, ES&T

Bogdal et al., 2010, ES&T

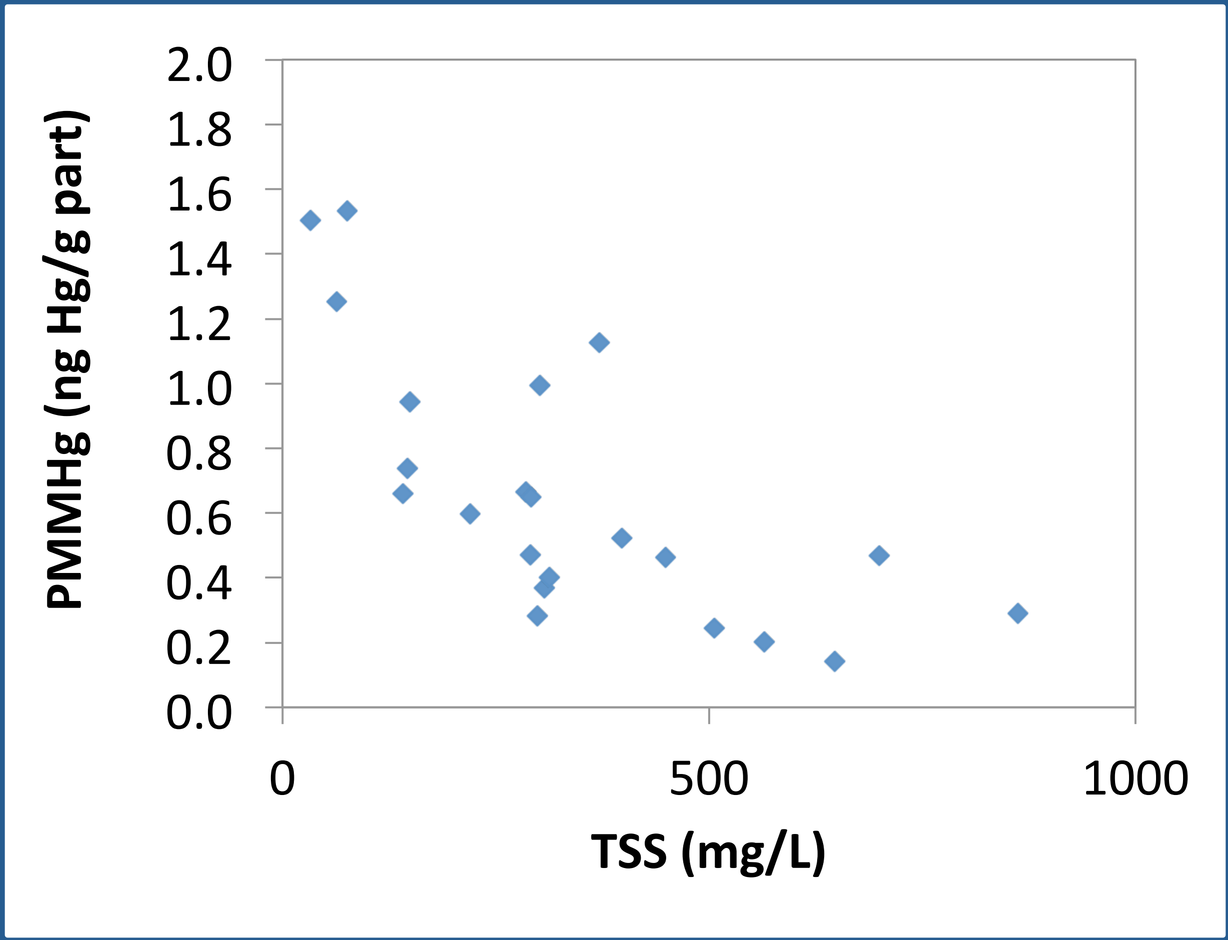
Atmospheric models show Hg transport to Alaska

Average elemental mercury surface concentrations for July 2001 (ng/m3)



GRAHM (Global/Regional Atmospheric Heavy Metals Model) simulation – Ashu Dastoor, Meteorological Service of Canada,Environment Canada

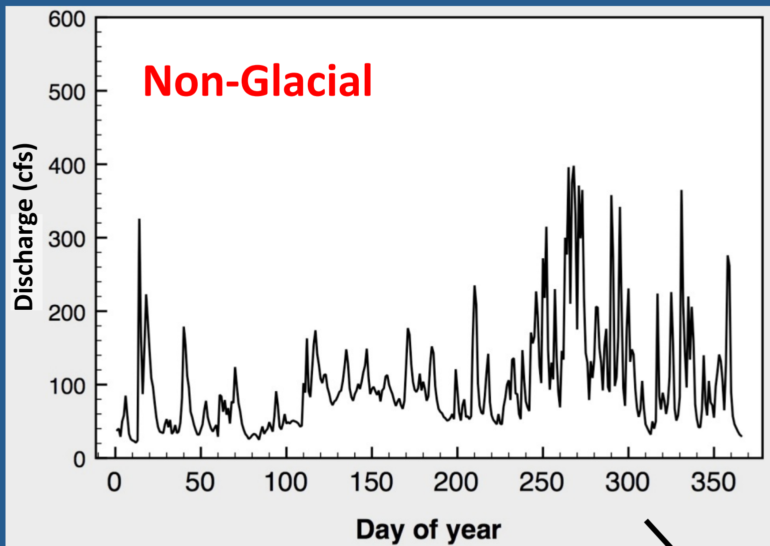
Glacial Monomethyl Hg export

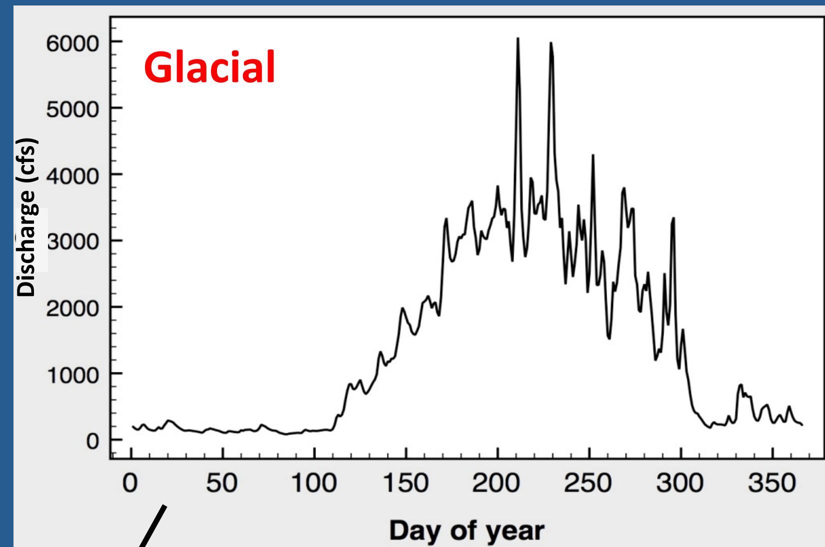


Vermilyea et al., unpublished

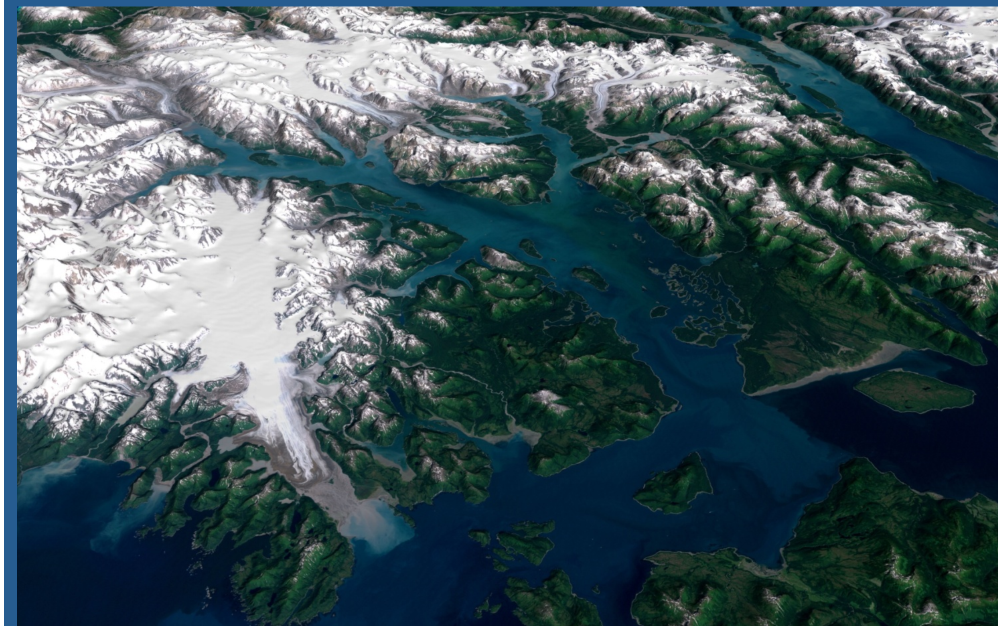
Runoff from glaciers is unique amongst terrestrial ecosystems:

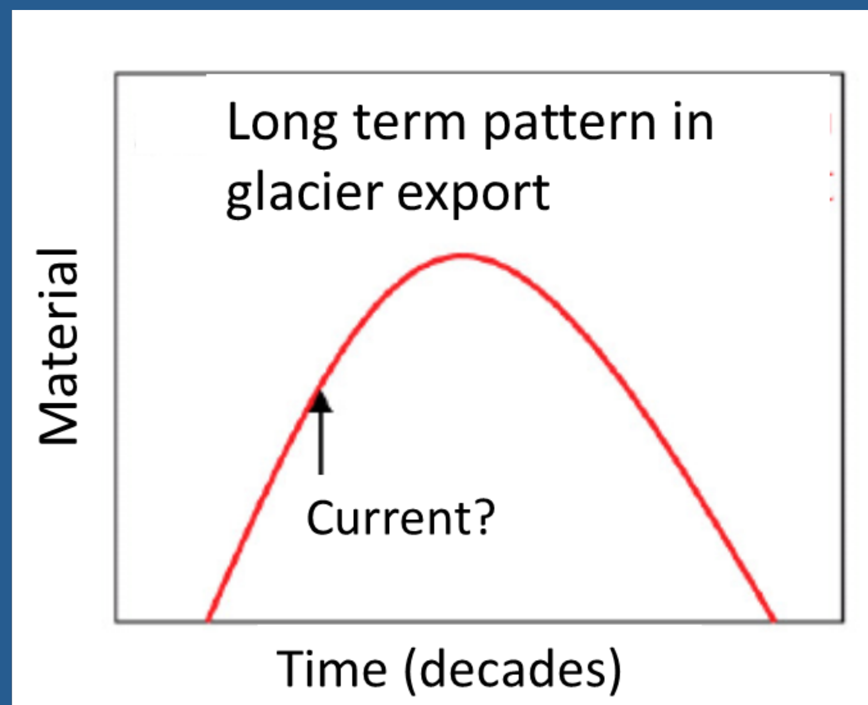
- bioavailable organic matter
- nutrients (P)
- micronutrients (Fe)
- contaminants (Hg)

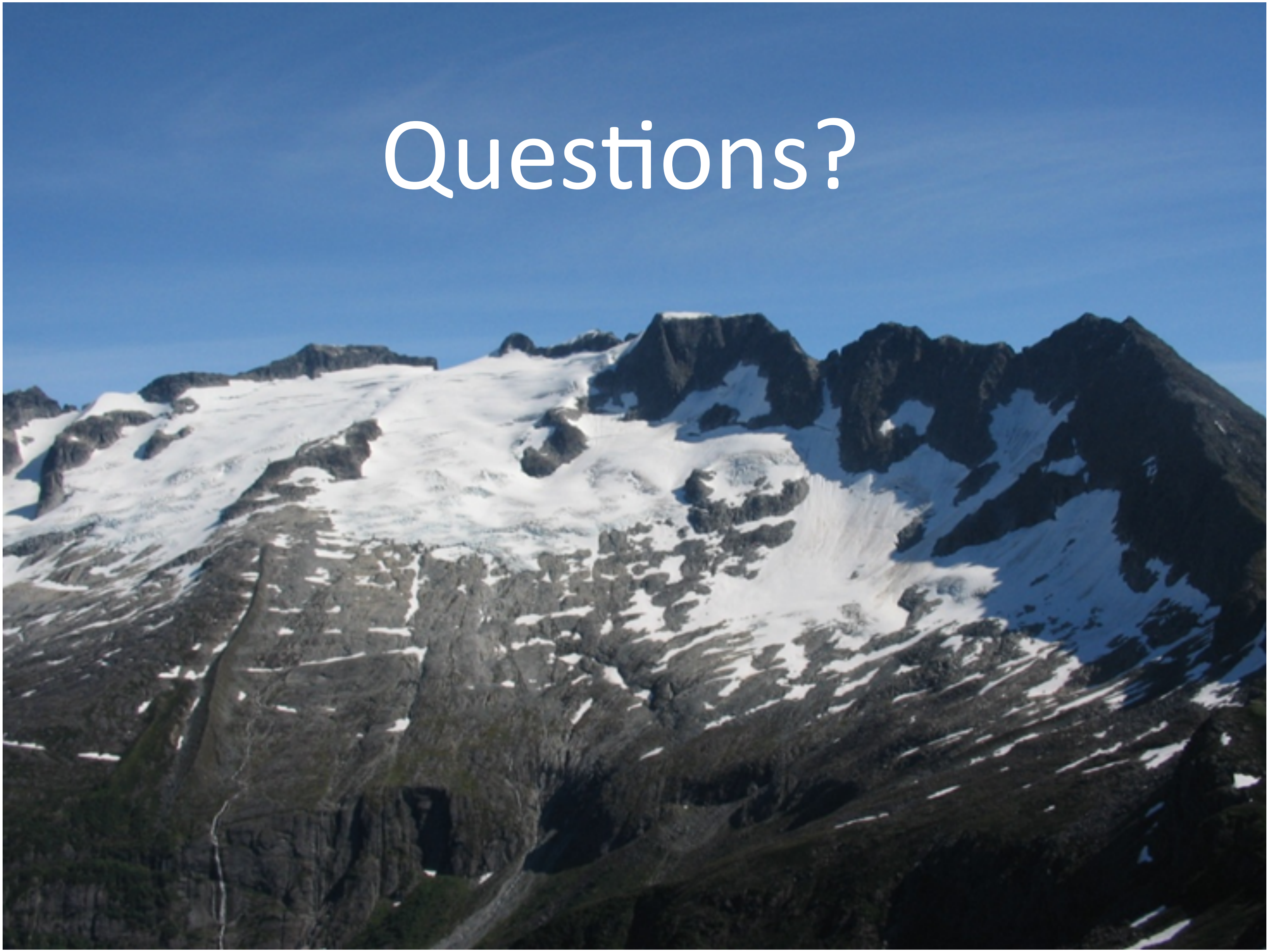

Non-Glacial
Discharge (cfs)
0
100
200
300
400
500
600
0
50
100
150
200
250
300
350
Day of year


Glacial
Discharge (cfs)
0
1000
2000
3000
4000
5000
6000
0
50
100
150
200
250
300
350
Day of year

Future Impacts






Questions?